Preliminary Investigations of the Use and Status of Instream-Flow-Needs Methods in Ontario with Specific Reference to Application with Hydroelectric Developments

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2005

PRELIMINARY INVESTIGATIONS OF THE USE AND STATUS OF INSTREAM-FLOW-NEEDS METHODS IN ONTARIO WITH SPECIFIC REFERENCE TO APPLICATION WITH HYDROELECTRIC DEVELOPMENTS

By

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ABSTRACT

The flow requirements of a river/stream is defined as the amount of water required to protect the structure and functioning of that ecosystem and to ensure the ecologically sustainable development and utilization of the water resource. There is considerable activity in Ontario, at the present time, in using and evaluating instream-flow-needs (IFN) methods for fish. IFN methods vary in nature and complexity, and thus in the conditions under which they can reliably predict when aquatic environments (*i.e.,* fish and fish habitat) are protected. This document provides: (1) a review of legislation relevant to IFN in Ontario; (2) a summary of the hydroelectricity issue in Ontario, with an emphasis on the Ontario Ministry of Natural Resources Waterpower Project and the implications to DFO and IFN assessments; and (3) a summary of the general kinds of IFN assessment methods with recommendations for selecting specific approaches.

RÉSUMÉ

On entend par exigences de débit d'une rivière ou d'un cours d'eau la quantité d'eau requise pour protéger la structure et le fonctionnement de cet écosystème et pour assurer l'utilisation et le développement durable sur le plan écologique de la ressource en eau. À l'heure actuelle, on observe une activité considérable en Ontario dans l'utilisation et l'évaluation de méthodes d'estimation des besoins en débit pour les poissons. Ces méthodes varient en nature et en complexité et donc selon les conditions dans lesquelles elles peuvent prédire de manière fiable quand les milieux aquatiques (*c.-à-d.* les poissons et leur habitat) sont protégés. Le présent document fournit : (1) un examen des lois pertinentes à l'estimation des besoins en débit en Ontario; (2) un résumé du dossier de l'hydroélectricité en Ontario, l'accent étant mis sur le projet d'énergie hydroélectrique du ministère des Richesses naturelles de l'Ontario et ses conséquences sur les évaluations du MPO et des besoins en débit; et (3) un résumé des types généraux de méthodes d'évaluation des besoins en débit avec des recommandations pour choisir des méthodes particulières.

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1.0 INTRODUCTION

Riverine systems require water to maintain ecological integrity. The flow requirements of a river/stream is defined as the amount of water required to protect the structure and functioning of that ecosystem and to ensure the ecologically sustainable development and utilization of the water resource (Metcalfe *et al.*, 2003). At the present time, there is considerable activity in Ontario in using and evaluating instream-flow-needs (IFN) methods for fish. IFN methods vary in nature and complexity, and thus in the conditions under which they can reliably predict when aquatic environments (*i.e.,* fish and fish habitat) are protected. IFN methods and procedures are relatively well used in some parts of Canada, principally Alberta, British Columbia and Newfoundland. IFN assessments are becoming more common in Ontario as part of the process for obtaining permits to take water (PTW), as well as to assist in the planning process for new and old hydroelectric developments.

The new requirements for IFN assessments in Ontario have caused a flurry of activity in IFN research. In response to the relatively recent requirement for water-taking permits, Conservation Ontario received funding and is carrying out studies aimed at identifying IFN methods that are appropriate for determining instream flow needs of rivers, streams and creeks in southern Ontario when assessing surface water takings on a watershed scale. The Ontario Ministry of Natural Resources (OMNR) is recommending "holistic" methodologies for determining instream flow requirements based on the natural flow regime (OMNR, 2001, 2002) and is prescribing methods for simulating and characterizing those natural flows (Metcalfe *et al.*, 2003). There are, however, a large number of instream flow methodologies that can be used in a variety of scenarios, with differing levels of resolution and inherent risk of being over or under protective of the aquatic environment.

Given this backdrop, the intent of this document is to provide an overview of the state of the science of IFN assessments for hydroelectric developments. This document, therefore, provides: (1) a review of legislation relevant to IFN in Ontario; (2) a summary of the hydroelectricity issue in Ontario, with an emphasis on the Ontario Ministry of Natural Resources Waterpower Project and the implications to Fisheries and Oceans Canada (DFO)

and IFN assessments; and (3) a summary of the general kinds of IFN assessment methods with recommendations for selecting specific approaches.

Waterpower facilities have the potential to reduce the flow of water downstream of the structure by storing water. Waterpower facilities also have the potential to increase flows for periods of time as water is released from storage during power generation. The altered flow regimes (lower low flows and higher high flows) impact on both upstream and downstream fish habitats in a variety of ways that include physical and chemical habitat alteration, and that differ from those impacts typically associated with water takings. A review of IFN methods appropriate to waterpower facilities is, therefore, warranted.

This document is intended for fish habitat biologists, specifically with DFO, to provide a "primer" on the IFN issue. Numerous reports and manuals exist that can provide detailed reviews and recommendations of specific methodologies. Those materials are cited throughout this document and should be read when full methodological detail or understanding is required.

2.0 LEGISLATION AND POLICY PERTAINING TO HYDROELECTRIC DEVELOPMENTS IN ONTARIO

Several pieces of federal and provincial legislation are relevant to hydroelectric developments in Ontario. They include:

- Federal
  - *Fisheries Act*
  - *Navigable Waters Protection Act*
  - *Species at Risk Act*
  - *Migratory Birds Convention Act*
  - *Canadian Environmental Assessment Act*
- Provincial
  - *Lakes and Rivers Improvements Act*
  - *Endangered Species Act*

- *Environmental Assessment Act*
- *Public Lands Act*
- *Ontario Water Resources Act*

Each of these pieces of legislation is reviewed below, with an emphasis on the significance to hydroelectric developments.

2.1 Federal Legislation and Policy

2.1.1 *Fisheries Act*

The *Fisheries Act* protects fish and fish habitat in Canada. "Fish" includes both species considered to be part of recreational, commercial and/or aboriginal fisheries, as well as forage species (including invertebrates) that directly or indirectly support those fisheries. Fish habitat includes all wetted habitats that support fish species directly or indirectly. The specific sections of the *Fisheries Act* that pertain to hydroelectric developments and potential water flow issues are listed in Table 1 below. All hydroelectric developments have the potential to interact directly or indirectly with fish or fish habitats, and will require some form of environmental review. Those that are considered to cause harmful alteration, disruption or destruction (HADD) of fish habitat will require an authorization from DFO under the *Fisheries Act*, and thus a federal Environmental Assessment (EA) under the *Canadian Environmental Assessment Act* (CEAA).

Table 1. Fisheries Act sections applicable to the management of flows.

FA Section	Objective
20	Ensures safe passage for fish.
22	Ensures safe fish passage, and the maintenance of sufficient flows to protect fish habitat downstream.
27	Ensures the unobstructed passage of fish through a waterway.
30	Ensures that fish screens are in place and prevent fish from entering water intakes (including at hydro facilities) in specific situations.
32	Prohibits the destruction of fish by any means other than fishing.
35	Prohibits works or undertakings that result in the harmful alteration, disruption or destruction (HADD) of fish habitat, except when authorized by the Minister or his delegate.

2.1.2 Navigable Waters Protection Act

Transport Canada (Canadian Coast Guard) protects the use of navigable waters through the *Navigable Waters Protection Act*. The Act ensures safe and unobstructed navigation in canals and other waterbodies that are altered as a result of the construction of any work. "Works" defined in the Act, and that are relevant to hydroelectric developments, include:

- any bridge, boom, dam, wharf, dock, pier, tunnel or pipe and the approaches or other works necessary or appurtenant thereto
- any dumping of fill or excavation of materials from the bed of a navigable water
- any structure, device or thing, whether similar in character to anything referred to in this definition or not, that may interfere with navigation

Any named works built or placed in, on, over, under, through or across any navigable water require approvals from Transport Canada, and will trigger the EA process through CEAA.

2.1.3 Species at Risk Act

The *Species at Risk Act* (SARA), administered by Environment Canada, protects designated species at risk in Canada. The list of species at risk is based on the classification system used by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and will be periodically updated as species status assessments and re-assessments become available. Species listed as extirpated, endangered or threatened under Schedule 1 of the Act are protected on federal lands, and wherever they occur if they are governed by other federal legislation (e.g., *Fisheries Act, Migratory Birds Convention Act*). Sections 33 and 58 of the Act also protect the residences (e.g., dens or nests) and critical habitat of these listed species.

Before hydroelectric projects are initiated, Environment Canada and the OMNR must be consulted in order to identify any potential SARA species concerns in the project area. Projects that require an environmental assessment under an Act of Parliament will have to take into account the project's effects on listed wildlife species at risk and their critical habitats. The assessment must include recommendations and mitigation measures in order to reduce or avoid adverse effects, and to monitor the impact of the project. The project plan must respect species recovery strategies and action plans developed under the Act. Recovery strategies set out the population goal and objectives, offer approaches to counter or mitigate

known threats to the survival of the species, identify the species' critical habitat, and set time lines for the preparation of the action plan. Action plans implement recovery strategies.

2.1.4 *Migratory Birds Convention Act*

Environment Canada administers the *Migratory Birds Convention Act* which prohibits the killing of migratory birds or the destruction of their eggs or nests, except during specific periods for specific game species. Environment Canada, with respect to hydroelectric developments, does not engage in reviews of projects except through the EA process if triggered by another federal agency. Because hydroelectric projects occur in riverine environments, and because most migratory waterfowl typically use lacustrine environments, negative interactions between hydroelectric projects and migratory birds should be relatively rare.

2.1.5 *Canadian Environmental Assessment Act* (CEAA)

The Canadian Environmental Assessment Agency administers the *Canadian Environmental Assessment Act*. Any hydro project, including the creation of a new dam or retrofit of an existing dam, that requires an approval under the federal *Fisheries Act*, *Navigable Waters Protection Act*, or other applicable legislation, triggers the requirement for a federal environmental assessment (EA). Other EA triggers include federal funding and use of Federal crown land for the hydro project. The federal agency acting as the "Responsible Authority" under the Act is required to conduct the EA, but may require the proponent to provide the background information in support of the EA. Completion of the federal EA process does not eliminate a proponent's requirement to carry out an EA at the Provincial level (2.2.2). Wherever possible, federal and provincial EAs will be harmonized.

2.2 Provincial Legislation and Policy

2.2.1 *Lakes and Rivers Improvements Act*

The *Lakes and Rivers Improvements Act* (1990) (LRIA) governs the management of Ontario's waters and the land under them. Through this Act, the Minister of Natural Resources has legislative authority over the operation of waterpower facilities, including preparation of water management plans (WMPs). The purpose of the Act is to manage the

use of the waters of the lakes and rivers of Ontario, to regulate improvements in them and to provide for:

- preserving public rights in or over water;
- protecting the interests of riparian owners;
- management of fish, wildlife and other natural resources dependent on such waters;
- preserving natural amenities; and,
- ensuring the suitability of the location and nature of improvements.

The LRIA applies to both private and public lands covered by water. Dams, channelization, diversions, in-stream ponds and by-pass ponds require permits through the LRIA on Crown, municipal and private lands.

Following the Ontario government's decision to establish a competitive market in the province's electricity sector in November 1999, an OMNR Waterpower Industry Task Force recommended the establishment of a Waterpower New Business Relationship (WNBR). The WNBR recognized the need to develop plans for the management of flows and levels on rivers having waterpower facilities and control dams. All owners of waterpower facilities are required to prepare water management plans under the LRIA. Water Management Plans are legally binding agreements between waterpower producers and the OMNR. Water management plans are developed according to the Aquatic Ecosystem Guidelines (AEG; OMNR, 2003), which, if implemented, are designed to protect aquatic resources from potential effects associated with waterpower facilities and water control structures. Under the AEG, water management plans are to (1) take an "ecosystem" or holistic approach, (2) recognize the dynamic (variable) nature of ecosystems, (3) recognize the flow regime as the single most important controlling feature, (4) maintain and enhance the aquatic system, and (5) track effectiveness of management through monitoring programs (OMNR, 2003).

Water management plans come in two forms. "Complex" water management plans are required for systems where there are multiple sites (powerhouses, reservoirs, etc.), and where waterpower facilities exert significant controls over water levels and thus have significant potential to impact on the local environment (I. Crawford, OMNR, pers. comm.). There are 18 complex plans scheduled for completion by the end of March 2005, covering 80+

facilities (Table 2). One complex plan for the Madawaska River is complete. The planning teams are comprised of the proponent and OMNR. DFO is not part of the planning teams constructing the complex plans, but is on the steering committees that must approve the plans. DFO also provides advice to the planning teams as requested.

The second type of water management plans, *i.e.,* simple, are required on systems where there are few water control structures that exert minimal control over water levels and thus have little likelihood of ecological impacts. DFO is not involved in the development of these simple plans (F. McGuiness, OMNR, pers. comm.). As with complex plans, simple plans are to be completed by the end of March 2005. New facilities will trigger the water management planning process, as well as other regulatory requirements.

Table 2. River systems for which "complex" water management plans are being developed.

MNR Region	River System	MNR Region	River System
Southern	Bonnechere	Northeast	Abitibi
	Muskoka		Montreal-Matabitchuan
	Mississippi		South
	(Madawaska)[1]		Blind
Northwest	Eagle/Wabigoon		Spanish-Vermillion
	Nipigon		Wanapitei
	Kaministiquia		Mattagami
	Seine		Montreal
	Aguasabon		Michipicoten
			Mississagi

Notes
1 Plan completed for Madawaska River.

2.2.2 *Endangered Species Act*

Ontario's *Endangered Species Act* (ESA), protects the habitat of any species threatened with extinction as regulated under this Act, and protects the habitat of these species (www.ontarionature.org). The Lieutenant Governor in Council may make regulations

declaring any flora or fauna to be threatened with extinction. Those species that have been evaluated as being at risk in Ontario and regulated under the ESA or other applicable Acts are on the "list of designated species at risk in Ontario" (SARO List). Species on this list are designated as special concern (vulnerable), threatened, endangered, extirpated or extinct (OMNR, 2002). It is prohibited for any person to wilfully kill, injure, interfere with or take any species of fauna or flora declared in the regulations to be threatened with extinction. The habitat of these species is also protected under this Act. Before hydroelectric projects are initiated, the OMNR must be consulted in order to identify any potential SARO species concerns in the project area.

2.2.3 *Environmental Assessment Act*

Hydro facilities that generate < 200 MW (*i.e.,* Category B Projects) are generally not required to prepare individual EAs if they complete the Environmental Screening Process as per Ontario Ministry of the Environment (OMOE) (2001). Facilities that generate > 200 MW (*i.e.,* Category C Projects) are required to complete individual EAs as per MOE (2001) requirements. New facilities must also meet the requirements of the OMNR Waterpower Program Guidelines (AEGs). Modifications to existing facilities which result in an increase in the capacity of the facility by 25% or more are considered significant modifications that are subject to the screening (< 200 MW) or individual (>200 MW) EA processes.

2.2.4 *Public Lands Act*

Proponents of new waterpower facilities require approvals from the OMNR under the *Public Lands Act* if Crown land is required to create reservoirs.

2.2.5 *Ontario Water Resources Act*

Water takings in Ontario are governed by the *Ontario Water Resources Act* (OWRA) and the Water Taking and Transfer Regulation (O. Reg. 387/04) a regulation under the Act. Section 34 of the OWRA requires anyone taking more that a total of 50,000 litres of water a day, with some exceptions, to obtain a Permit from a Director appointed by the Minister for the purposes of Section 34. Proponents of new waterpower facilities may be required to obtain a Permit To Take Water (PTTW) from the OMOE under the *OWRA* .

3.0 HYDROELECTRIC DEVELOPMENTS

In 2002, there were 439 electrical generating units contained within 143 hydroelectric facilities distributed in 47 tertiary watershed in Ontario (Statistics Canada, 2002; Figure 1). Those facilities produce about 26% of the province's electrical energy supply, with an installed capacity of over 8,000 Megawatts. The hydroelectric generation facilities in operation in Ontario can be classified into four types: run-of-the-river, peaking (storage), intermediate, and cascade systems.

Run-of-the-River (ROR) generating facilities are usually located on small dams with a low head. Head ponds, if present, have limited direct storage capacity. ROR facilities (*e.g.,* Figure 2a) can involve low weirs or dams to channel water, but often there is no dam because water is not "stored," rather, flow rates and volumes are natural. Electrical generation at ROR facilities varies with seasonal hydrological patterns. Large volumes of water pass through these low-head systems in order to generate a useful amount of electricity. These systems are generally used to help meet the baseload demands for power. An example of a ROR facility is the Carmichael Dam located on the Groundhog River.

Peaking or **storage** facilities have large storage capacity (*i.e.,* forebays) and/or upstream reservoirs in which water can be held back, stored and released at times to meet peak electrical demand (*e.g.,* Figure 2b). Discharge can be discontinuous, and typically does not mimic natural flow patterns. Dams or reservoirs can also be used to impound water during rainy periods for release during dryer periods so that a stable supply of power can be provided. Examples in Ontario include the Little Long Dam on the Mattagami River.

Facilities that combine characteristics of run-of-the-river and peaking operations are known as "**intermediate**" or "**modified peaking facilities**". Water can be stored in the head pond and discharged during some peak periods of energy demand. These facilities are capable of storing some portions of the daily inflow during off-peak hours, but not to the extent of full peaking operations. An example is the Kipling Dam on the Mattagami River.

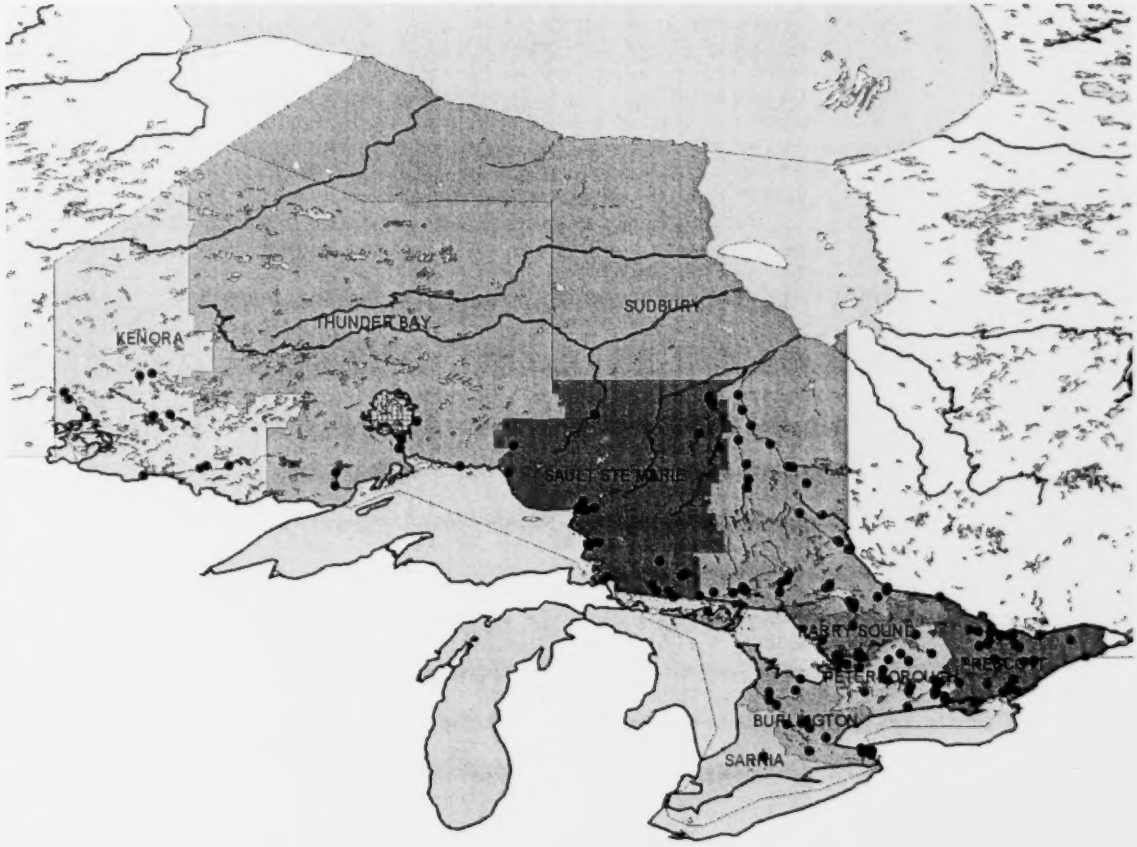

Figure 1. Locations of hydroelectric facilities in Ontario.

Figure 1. Locations of hydroelectric facilities in Ontario.

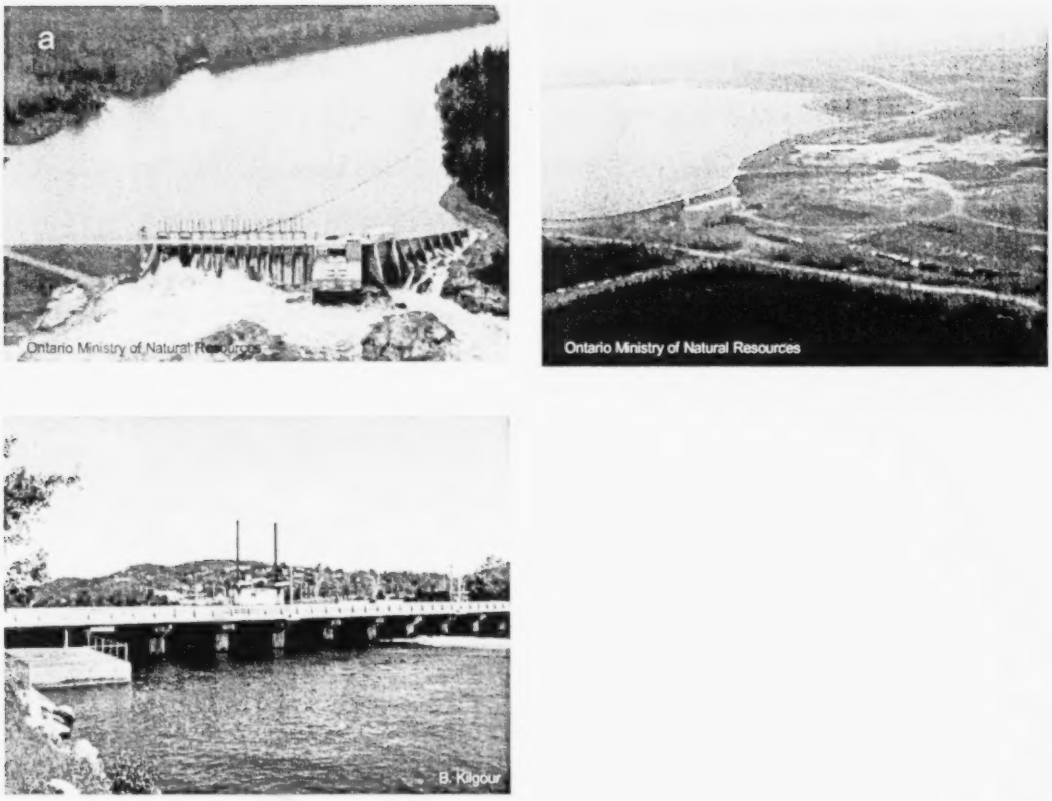

Figure 2. Photographs of various dam types. (a) run-of-the-river facility - Carmichael Dam – located on the Groundhog River; (b) peaking facility - Little Long Lake Dam – on the Mattagami River; (c) control structure – Temiscaming Dam – located on the Ottawa River between Ontario and Quebec.

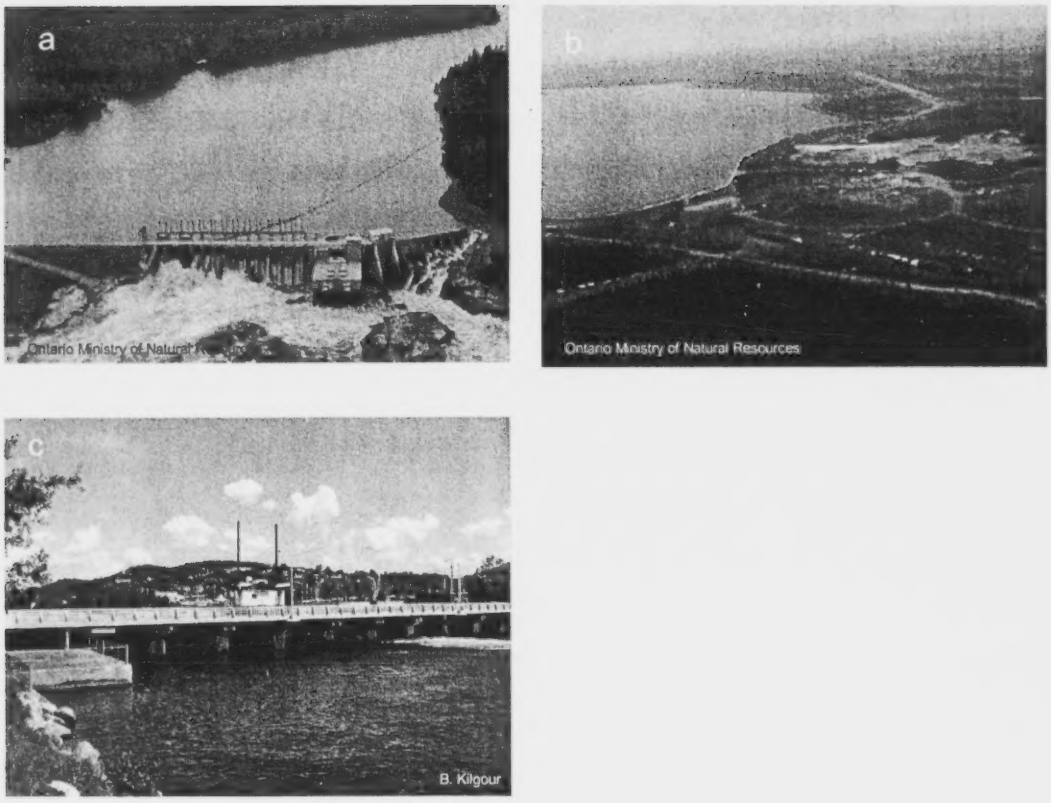

Figure 2. Photographs of various dam types. (a) run-of-the-river facility - Carmichael Dam – located on the Groundhog River; (b) peaking facility - Little Long Lake Dam – on the Mattagami River; (c) control structure – Temiscaming Dam – located on the Ottawa River between Ontario and Quebec.

Some of Ontario's waterpower facilities are organized in a "**cascade system**" in which the stored water in a system is cascaded through a number of downstream facilities. The release of water from an upstream reservoir will move through a series of downstream operations with a time delay corresponding to distance between facilities and flow rates. Thus, downstream operations are not necessarily operating independently or solely on their own stored capacity and must therefore be operated in a coordinated fashion. Examples of cascade systems include the facilities on the lower Mattagami and the Madawaska rivers.

Some hydroelectric systems include structures (dams) that are not used to generate electricity, but are rather used to regulate flows in a system (*e.g.*, Figure 2c). These **water control dams** are often incorporated into the design of reservoir systems, and have many of the same (though perhaps to a reduced scale) operational attributes associated with facilities that generate power. IFN below these structures must also be considered.

Facilities with reservoirs can also be used for "pumped storage". These facilities use excess electrical system capacity, generally available at night, to pump water from one reservoir to another reservoir at a higher elevation. During periods of high or peak demand water is released from the higher to the lower reservoir, through turbines, which can help meet the demand at critical periods. An example is the Sir Adam Beck complex on the Niagara River.

4.0 INSTREAM FLOW NEEDS METHODS

Reviews of instream flows needs have been produced in several countries including Australia (Karim *et al.*, 1995), the US (Stalnaker and Arnett, 1976; Estes and Orsborn, 1986), and South Africa (King *et al.*, 1999). Several reviews have also been conducted in Canada (*e.g.*, Scruton *et al.*, 2004) including in Alberta (IFNC, 1999), Newfoundland (JWEL, 1996a,b, 1997), the Maritimes (Caissie and El-Jabi, 1995), British Columbia (Korman *et al.*, 1994; Higgins *et al.*, 2001) and Ontario (OMOE, 1999; Morrison and Smokorowski, 2000; Gartner Lee, 2002; Metcalfe *et al.*, 2003). The Instream Flow Council recently published a comprehensive review of 29 modeling tools (IFC, 2002), while the Canadian Water Resources Journal recently produced a special issue on the state-of-the art of fish habitat modeling in rivers (Leclerc *et al.*, 2003).

Instream flow needs methods (also called environmental flow methodologies, Tharme, 2003b) can be classified into five broad categories: (1) hydrological; (2) hydraulic rating; (3) habitat simulation; (4) natural flow regime; and (5) holistic. Common examples of each of these four broad categories are provided in Table 3. An overview of the general approaches is provided, as is a summary of the benefits and limitations of each.

Table 3. Instream flow methodologies by major category.

Category	Method	Source
Hydrologic	Tennant (Montana)	Tennant (1976)
	Aquatic Base Flow (ABF)	Larsen (1981)
	Flow Duration Curve	Bounds and Lyons (1981), for example
	7Q10	IFC (2002), for a review
	7Q2	Belzile *et al.* (1997)
	Median Monthly Flow (Q50)	Larsen (1981), Caissie and El-Jabi (1995)
	10^{th} percentile	Loar and Sale (1981), Smakhtin (2001)
Hydraulic Rating	Wetted Perimeter Inflection Point	IFC (2002), for a review
	Transect Method	Dunham and Collotzi (1975), Cooper (1976)
	Simplified Staff Gauge	Karim *et al.* (1995)
	R-2 Cross	Karim *et al.* (1995)
	Water Surface Profile	Karim *et al.* (1995)
Habitat Simulation	Instream Flow Incremental Methodology (IFIM)	Stalnaker *et al.* (1995)
	Habitat Quality Index	Binns (1982)
	RIVER2D Model	Katopodis (2003)
	HABIOSIM	Referred to in Katopodis (2003)
	CASIMIR	Jorde *et al.* (2000)
	River System Simulator (RSS)	Alfredsen (1998)
Holistic	Building Block Method (BBM)	King and Louw (1998)
	Holistic Approach	Arthington (1998)
Natural Flow Regime	Natural Flow Regime	Petts (1996), Poff *et al.* (1997), Richter *et al.* (1997)
	Range of Variability Approach (RVA)	IFC (2002)

4.1 Hydrological

4.1.1 Overview

Hydrological instream flow methods are generally simple, desktop exercises that use historical flow records, and some rules-of-thumb relationships between fish, habitat and flows, to justify minimum flows in a system. Historical flow data are taken from the river of interest, or is estimated based on relationships between catchment size and flow. Some fraction of the historical or predicted flow is then used as the proposed minimum flow. These methods are typically rapid, and do not take a lot of effort to produce a recommended minimum flow. These methods are considered most appropriate as reconnaissance-level tools that can provide a very general estimate of minimum acceptable flows (Tharme, 2003b).

4.1.2 Examples

The most common of the hydrologic methods is the "Montana" or "Tennant" Method (Tennant, 1976). The Tennant Method is used in 16 states (Reiser *et al.*, 1989), and is one method recommended by the OMOE (1999) to support water takings. The Tennant Method recommends that the minimum flows be set relative to the mean annual flow (MAF) as shown in Table 4.

Table 4. Instream flow regimes for fish, wildlife, recreation and related environmental resources (from Tennant, 1976).

Narrative Description of Flows[1]	Recommended Base Flow[2] as a Percent of Mean Annual Flow	
	October- March	April-September
Flushing (maximum)	200	200
Optimum	60 – 100	60 – 100
Outstanding	40	60
Excellent	30	50
Good	20	40
Fair	10	30
Poor	10	10
Severe Degradation	< 10	< 10

Notes

1 "Most appropriate description of the general condition of the streamflow for all the parameters listed in the title."

2 Tennant's term; presumed to mean lowest fixed flow, not a hydrological term.

The Aquatic Base Flow (ABF) Methodology was developed in New England. An approximation of the historic unregulated median August baseflow is used to represent the minimum instantaneous instream flow requirement, unless other seasonal releases are required to protect fish spawning and egg incubation (Larsen, 1981; IFN, 2002). Flows during August are assumed to represent a natural limiting period due to reduced living space, high water temperatures and low dissolved oxygen. Flows equal to the average August minimum are, therefore, considered adequate to perpetuate aquatic organisms.

Instream flows can be derived from flow duration curves, which are in turn derived from hydrological records. Flow duration curves indicate the fraction of flows that exceed specific flow volumes. Bounds and Lyons (1979), for example, recommended minimum flows of 40% of the monthly median (Q50) to maintain aquatic habitats between October and March, and 60% of the Q50 for spawning and hot summer months This median monthly flow method (or Q50) has been applied in Atlantic Canada (Caissie and El-Jabi, 1995). Other general rules-of-thumb based on flow-duration curves include (1) 25% of the mean annual flow (MAF), (2) the 7Q10 (*i.e.*, 10 year low of 7-day average flows) (King, 2004), (3) the 7Q2 (2 year low of 7-day average, Belzile *et al.*, 1997), and (4) 10^{th} percentile of monthly flows (Loar and Sale, 1981).

4.1.3 Benefits and Limitations

Instream flow methods based on hydrology tend to provide estimates of minimum flows with a minimum of effort. They rely on models or knowledge of the relationships between flow volumes and aquatic habitat or biology. Those models are generally more valid when applied to areas close to where they were developed or calibrated. When applied outside the area used for calibration, these models will over or underestimate the flows required to protect aquatic habitats and species. IFC (2002) provides an excellent overview of the concerns associated with hydrologic models and approaches. In general, these methods are considered suitable for "low-risk" situations when, for example, there are no "important" or "key" species of fish to protect, or when species living in a river are tolerant of manipulated conditions. These methods are typically not used where there is higher "risk" such as when

there is a key sport or commercial species in a system that is sensitive to flow volume and velocity manipulations.

4.2 Hydraulic Rating

4.2.1 Overview

Hydraulic rating methods involve the correlation of various hydraulic parameters (e.g. hydraulic geometry; Gartner Lee, 2002) to physical habitat features. The parameters typically considered in these methodologies include wetted perimeter, water surface width, velocity, depth, cross-sectional area, and substrate. Data for these parameters are collected for different flow conditions along transects across a stream. The transects chosen are selected to be representative of specific types of habitat. The data are then used to define the habitat and form the basis for flow recommendations. This is done through the development of habitat-discharge curves that describe the variation of a physical habitat parameter with discharge at a specific location. The relationships between discharge and habitat features described by these curves are presented graphically, with discharge being represented on the horizontal axis and the habitat parameter on the vertical axis.

Once these relationships have been defined two different approaches based on a single attribute measurement can be used to derive instream flow recommendations from the habitat response curve. In the first approach, the minimum discharge can be set at the flow which produces a fixed percentage reduction in a particular habitat attribute relative to that associated to a reference flow (e.g. 20% reduction in the wetted parameter might be the maximum allowable degradation (i.e. habitat retention criterion, Bartschi 1976). The second approach, the inflection point criterion, relies on the determination of the inflection point being defined as that point where a major change in slope, as it relates to the way the habitat responds to the flow, occurs. Such a point might occur where a steep reduction in the wetted perimeter occurs. The discharge that corresponds to that point could be defined as the minimum discharge.

4.2.2 Examples

A commonly used hydraulic method is the Wetted Perimeter Inflection Point Method. It is used in the US (Reiser *et al.*, 1989) and Canada (OMOE, 1999). The wetted perimeter is the

wetted width which is submerged across a cross-section of the stream. As discharge increases, water depth increases and the wetted perimeter also increases as more of the bank becomes inundated. The rate of increase in wetted perimeter is not constant and depends on channel geometry. As discharge increases, the wetted perimeter increases up to the point where water fills the streambed. In a case where the stream banks are vertical, increased discharge no longer increases the wetted perimeter. The same is true in reverse where decreased discharge tends to reduce wetted perimeter. It is commonly found that when discharge decreases, wetted perimeter is reduced proportionately as dictated by channel morphology. As the broad 'bottom' of the streambed becomes exposed the decrease in wetted perimeter is accelerated. This change in the rate of decrease in wetted perimeter marks the inflection point and defines a critical point above which the recommended minimum stream flow is often set. Measurements of the wetted perimeter are usually taken at riffles because they tend to have more rectangular cross-sectional profiles than other stream sections, and tend to be shallower and therefore proportionately more sensitive to changes in flow (PPWB, 1999). It is assumed that minimum flows that protect riffle habitats also protect other stream habitat types (*i.e.*, pools, runs, etc.; Gartner Lee, 2002). Minimum flows at riffles are designed to ensure that:

- all substrates are covered with water, thus providing maximum area for food production;
- there will be running water at the shore where undercut banks; exposed roots, etc. will provide cover and rearing habitat;
- the water width will be sufficient to catch all or most of the terrestrial insect fallout and leaf detritus;
- streamside grasses and shrubs at or in the water margins will provide cover and habitat; and,
- the effect of solar radiation on water temperature will be reduced because of shade from banks and overhead canopy.

In addition to these methods, which measure single attributes, the U.S. Forest Service has also developed procedures involving multiple attributes (Dunham and Collotzi 1975, Cooper 1976). These procedures use transect type data sets based on quantifications of subjective evaluations made by field personnel (i.e. measures of stream and flow characteristics are

rated subjectively). Each of four components of the habitat – namely, pool measure (percentage of stream width with pool type habitat), pool structure (quality of pool habitat based on depth, cover, etc.), substrate type, and riparian environment (e.g. type and density of growth) is rated by integer values from 1 to 4. The average of these four variables represents the habitat value index. A graph of habitat index, as a function of flow, is then constructed. The instream flow requirement is defined as the discharge resulting in 80 percent of the habitat index, as it exists at bank-full reference flow.

The Simplified Staff-Gauge Analysis approach was developed as a relatively simple method for quantifying the relationship between habitat conditions and stream flow. This approach is based on a stage-discharge curve, with the transect location being based on ecological criteria for identifying critical habitat for a target species or life stage. A staff gauge is established at the location relevant to the critical habitat and the stage read for various flows. The instream flow requirement is then determined by applying a specific habitat criterion, such as a minimum depth threshold, at the gauge location (Karim *et al.*, 1995; Loar and Sale, 1981).

The R-2 Cross method was developed by the Region 2 office of the U.S. Forest Service for predicting hydraulic conditions which could be expected at undocumented discharges. The calculations are based on the Manning equation for open channel flow and are used to describe conditions at a single transect. Field data in the vicinity of a transect are used to calculate the coefficient of roughness (n) and, assuming that values of n and slope (s) are independent of flow, an iterative program is applied to find values of average velocity, wetted perimeter, cross-sectional area, maximum depth, or hydraulic radius at discharges other than those contained in the calibration data set. These data are then used to derive a habitat-discharge curve. The original method was subsequently modified to use empirical equations relating to roughness and slope to hydraulic parameters such as discharge or hydraulic radius. The recommendations for instream flow requirements from this method are based on habitat-discharge curves and use either a habitat retention criterion or inflection point criterion (Karim *et al.*, 1995).

The Water Surface Profile (WSP) Hydraulic Simulation method is based on a hydraulic simulation model for predicting water surface elevations. It has been adapted for instream flow management to predict changes in such physical habitat parameters as depth, velocity, and wetted perimeter for various discharges. The model uses three basic equations – namely, continuity of discharge between transects, Mannings equation, and the Bernoulli energy equation, to link transect data to predict depths and velocities longitudinally through a stream reach. This method can also include prediction of mean water column velocities for multiple subsections of transects (Karim *et al.*, 1995).

4.2.3 Benefits and Limitations

Hydraulic methods are useful because they can be applied in regions where historical information is lacking and are useful at the site-specific level of assessment (*i.e.,* measure can be taken directly: there is no reliance on previously collected data). They are intermediate in cost and complexity between discharge methods and habitat preference methods (Gartner Lee, 2002; PPWB, 1999). As with hydrologic methods, hydraulic ratings methods result in a single recommended minimum stream flow value

4.3 Habitat Simulation

4.3.1 Overview

These models are similar to the hydraulic rating methods which have more general habitat requirements as the focus; habitat simulation methods have species-specific habitat features as the focus.

4.3.2 Examples

Several models are available and can be used to predict the suitability of habitat for fish species. The most widely known and most commonly used method (at least in the U.S.) is the Physical Habitat Simulation Component (PHABSIM, Stalnaker *et al.*, 1995). PHABSIM requires the collection of habitat data (typically depth, flow velocity, substrate, cover) along cross sections, hydraulic simulation to estimate habitat conditions at different flows, and species suitability criteria to evaluate habitat conditions at the various flows. Field measurements of depth, flow, substrate and cover are taken along cross sections at different flows. These data are used to calibrate hydraulic models. The models are used to predict

depths and velocities at flows different than those used in the calibration. Under each flow regime, each stream cell is weighted as to its suitability for the identified species (again based on models of suitability). Data requirements are not necessarily onerous, and depend on the inherent risk associated with the project or water management (Stalnaker *et al.*, 1995). The commercial equivalent of PHABSIM is RHABSIM (Riverine Habitat Simulation).

Other habitat simulation models, based on linking hydraulics and habitat suitability information are available. RIVER2D was developed in Alberta (Katopodis, 2003) and is a two-dimensional depth averaged hydrodynamic model that has been customized for fish habitat evaluation studies, consisting of four individual programs. As with PHABSIM, the model uses data on river water depths and velocities and extrapolates depths and velocities to unmeasured habitats. Coupling habitat suitability indices for individual fish species to the model of depth and velocity can be used to estimate the area suitable for the species of interest. In the Kananaskis River, for example, the RIVER2D modeling exercise for the Pocaterra Power Plant consisted of:

1. collection of hydraulic and biological data;
2. calibration of the hydraulic models;
3. creation of habitat suitability functions for mountain whitefish and brown trout;
4. calculation of habitat-flow relationships for each target life stage;
5. creation of flow scenarios to be evaluated; and,
6. development of a tool for calculating effective habitat and conducting effect habitat time series analysis.

In Europe, CASIMIR (Jorde *et al.*, 2000) is a popular tool used to model relationships between temporal and spatial patterns in river bottom shear stress and changes in discharge to habitat suitability for invertebrates. The river system simulator (RSS) is used in Norway (Alfredsen, 1998), while the river hydraulics and habitat simulation program (RHYHABSIM) is used in New Zealand.

A second type of habitat simulation model is based on correlating stream habitat features with the standing crop (biomass, abundance) of a species. An example of this type of analysis is Wyoming's Habitat Quality Index (HQI) as described by Binns (1982). The procedure is considered stream specific (Stalnaker *et al.*, 1995), but like any index of this nature could be used anywhere with the appropriate cautions.

The instream flow incremental methodology (IFIM) is often confused with PHABSIM (Stalnaker *et al.*, 1995). Rather than a specific model, IFIM is considered a general approach to solving the problem of instream flow needs. PHABSIM, and the other models, can be incorporated into IFIM (Stalnaker *et al.*, 1995). IFIM has five general steps: (1) problem identification, (2) study planning, (3) study implementation, (4) alternatives analysis, and (5) problem resolution. The U.S. Geological Survey (USGS) pro ' les a variety of software tools that can be used as part of the IFIM process including soiiware for developing habitat suitability indices (*e.g.,* HSI). The website also provides PHABSIM, SALMOD (simulates freshwater salmonid populations), the Stream Network Temperature Model (SNTEMP, which predicts water temperature from stream geometry, meteorology and hydrology), and the Stream Segment Temperature Model (SSTEMP, a scaled down version of SNTEMP). The IFIM process typically includes microhabitat models (such as PHABSIM, RIVER2D), and macrohabitat models that predict water temperature and water quality from hydraulic inputs.

4.3.3 Benefits and Limitations

Methods belonging to this class have generally been the methods of choice for high-risk management scenarios, where there has been a resource (fish species) of particular interest. These models are a "step up" from the hydraulic rating methods because they at least attempt to relate hydrological information to the habitat requirements of specific species. A major criticism of this class of method is the reliance on habitat suitability curves. Suitability curves are generally noisy and often do not adequately characterize the relationship between the standing crop of a species and the specific habitat attributes (see for example, Stanfield *et al.*, 2001; Caissie and El-Jabi, 2003). Suitability curves developed in one river also may not be appropriate or applicable in other systems. Suitability curves can be based on "intuition" rather than real data, and so should be used cautiously.

A second criticism of these kinds of models is their focus on "key" species. Many consider the protection of individual species to be inadequate and prefer the more holistic protection of all species where possible. Holistic approaches are described below.

4.4 Natural Flow Regime

4.4.1 Overview

The "natural flow regime" is the long-term unregulated pattern of flow magnitude, duration, seasonality and frequency (Metcalfe *et al.*, 2003). The natural flow regime is considered a major factor in determining the function, integrity and biodiversity of an aquatic system (Poff *et al.*, 1997). Maintaining the natural flow is, therefore, expected to protect the ecology of a river including all species, not just single "key" species.

4.4.2 Examples

The OMNR has adopted the natural flow regime as a guiding principle for establishing flow requirements for rivers affected by hydroelectric generating stations. In Ontario, Metcalfe *et al.* (2003), recommend establishing the natural flow patterns at waterpower facilities in the form of continuous daily flow time series. Natural daily flows are typically simulated based on data/flows for unregulated catchments from the Water Survey of Canada HYDAT database. The key flow parameters are considered to be minimum flows, bankfull flows, riparian flows and rate of change of flows. Metcalfe *et al.* (2003) recommend (1) the median flow for each month (or season) as the target minimum flow, (2) the flood frequency curve to determine the appropriate recurrence interval for bankfull and riparian flows, and (3) the simulated flow time series based on daily mean flows to calculate normal up-ramping and down-ramping rates.

The Range of Variability (RVA) approach differs slightly from the OMNR's approach to the "natural flow regime". The RVA method evaluates 30 hydrological parameters from a set of measured or synthesized daily flow measurements. A range of variation for the hydrological data set (*i.e.*, ±1 standard deviation from the mean or 25/75th percentiles) is then used as the flow management target. The RVA is currently being evaluated for use in southern Ontario for water taking permit requests by the Long Point Conservation Authority.

4.4.3 Benefits and Limitations

Methods based on simulation or mimicking of the natural range of variability in flows have the intention of protecting the ecosystem more holistically (*i.e.*, a broad variety or most species in the system), in contrast with other methods that typically target individual or key species. Scruton *et al.* (2004) suggest that research is still required to determine the components of the natural flow regime, and what magnitude of flow volumes are necessary to maintain the essential character of a river, while allowing some modification to the flow regime.

4.5 Holistic

4.5.1 Overview

Tharme (2003a) describes holistic methods as approaches to setting instream flow requirements incorporating ecological, social and economic considerations. The process typically requires considerable multidisciplinary expertise and formalized input through multi-stakeholder workshops or a consultative process. One or all social or environmental components may require detailed scientific investigation or analysis as part of the process.

4.5.2 Examples

A variety of agencies have formalized their specific holistic approaches. Some key examples include the Building Block Methodology (BBM) from South Africa (King and Louw, 1998), and the Benchmarking Methodology from Australia (Tharme, 2003a).

4.5.3 Benefits and Limitations

By their nature, holistic methodologies are designed to take into account a variety of stakeholders. At the ecosystem level, holistic methods are particularly designed to take into account the needs of all species, not just "key" species. In comparison to the other types of the methods that focus on simple habitat features or individual fish species, holistic methods should provide more comprehensive protection of aquatic resources. Holistic methods, however, do typically require meetings and consultation with multiple stakeholders, and can, therefore, be resource and time consuming.

5.0 RECOMMENDATIONS

Given the numerous instream flow methodologies available worldwide (or even in Canada), selecting specific tools or models requires justification. Several of the documents providing a review of methods recommend selecting a preferred method after considering the risk that the project (or facility) poses to the aquatic environment, and the rigour of the model or tool under consideration. Here, risk of ecological impairment (or habitat alteration, disruption or destruction) is a function of both the magnitude of the project and the sensitivity of the habitat. There are a variety of ways to classify aquatic habitats (JWEL, 2004). DFO currently classifies the sensitivity of drain habitats according to the scheme in Table 5. Sites with cold-water piscivorous species, for example, are considered more sensitive to a variety of disturbances including drain cleanout, and likely also hydroelectric development, than sites with warmwater benthivorous species. That scheme can be variously modified to suit a variety of needs and an attempt has been made to make it generic and applicable across Canada (*e.g.,* JWEL, 2004). The drain classification scheme is provided here only as an illustration of what is possible. DFO is also undergoing a process to classify the severity of projects (C. Stoneman, DFO, pers. comm.).

Table 5. Drain classification system used in southern Ontario (from DFO, 2001).

Type	Flow	Temperature	Species	Sensitivity[1]
A	Permanent	Cold/cool/unknown	No trout or salmon	Moderate
B/E	Permanent	Warm	Top predators &/or ecosystem indicators	Moderately High
C	Permanent	Warm	Forage fish	Low
D	Permanent	Cold/cool/unknown	Trout and/or salmon	High
F	Intermittent	n/a	n/a	Very low

Notes
1 Sensitivity ratings not provided by DFO (2001).

Knowledge of habitat sensitivity and project severity can be combined to select appropriate IFN methods. Most reviews of IFN methods (*e.g.,* IFC, 2002) recommend complex methods

(*e.g.*, habitat simulation or holistic) for highly complex projects with anticipated large impacts on flow volumes (*e.g.*, storage projects), or for sites with highly valued ecological resources (*i.e.*, anadromous salmon or trout). Less rigorous methods (*e.g.*, hydraulic simulation) are generally recommended for rivers with "poor quality" fish habitats or relatively benign effects on flows (*e.g.*, run-of-the river, water control structures).

Table 6 and Figure 3 illustrate how the various classes of models could be justified given habitat sensitivity and project complexity. As above, highly complex projects in a sensitive environment require a rigorous approach (*e.g.*, holistic or habitat simulation) that will ensure the long-term integrity of the natural environment, and that potentially balances ecological requirements with human socioeconomic considerations. Less complex projects in more tolerant environments may require less rigorous methods.

Table 6. Matrix of potential minimum IFN methods for severity and sensitivity of habitats.

Project Complexity	Severity of Impact	Habitat Sensitivity				
		High	**Moderately high**	**Moderate**	**Low**	**Very low**
Peaking	High	Holistic	Holistic	Holistic (PHABSIM)	Hydraulic Rating	No concerns
Run-of-the-River	Moderate		Holistic (PHABSIM)	Hydraulic Rating	Hydraulic Hydrological	
Channel Modifications	Low		Hydraulic Rating	Hydraulic Hydrological	Hydraulic Hydrological	
No Impact	No impact	No concerns				

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